THORNTON TRANSITIONAL RESERVOIR STORM WATER MANAGEMENT

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INTRODUCTION

Consoer Townsend Envirodyne Engineers, Inc (CTE) has completed the design of a multidisciplinary project for the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). The project will divert more than 80% of the 100-yr peak discharge of Thorn Creek (i.e. 6200 cfs) into an existing quarry located south of I-80/I-294 between Halsted Street and Indiana Avenue, in Thornton, Illinois (Figure 1). The project will be used in connection with the Tunnel and Reservoir Plan (TARP), shown schematically in Figure 2, one of the most important flood control and water pollution prevention projects in the Chicago Metropolitan area. The major goals of TARP are:

- Prevent flooding in Chicago Metropolitan area and the backflows into Lake Michigan
- Reduce or eliminate pollution of the various waterways in the area caused by combined sewer overflow
- Comply with the Federal and State environmental laws
- Accomplish results in the most cost effective manner

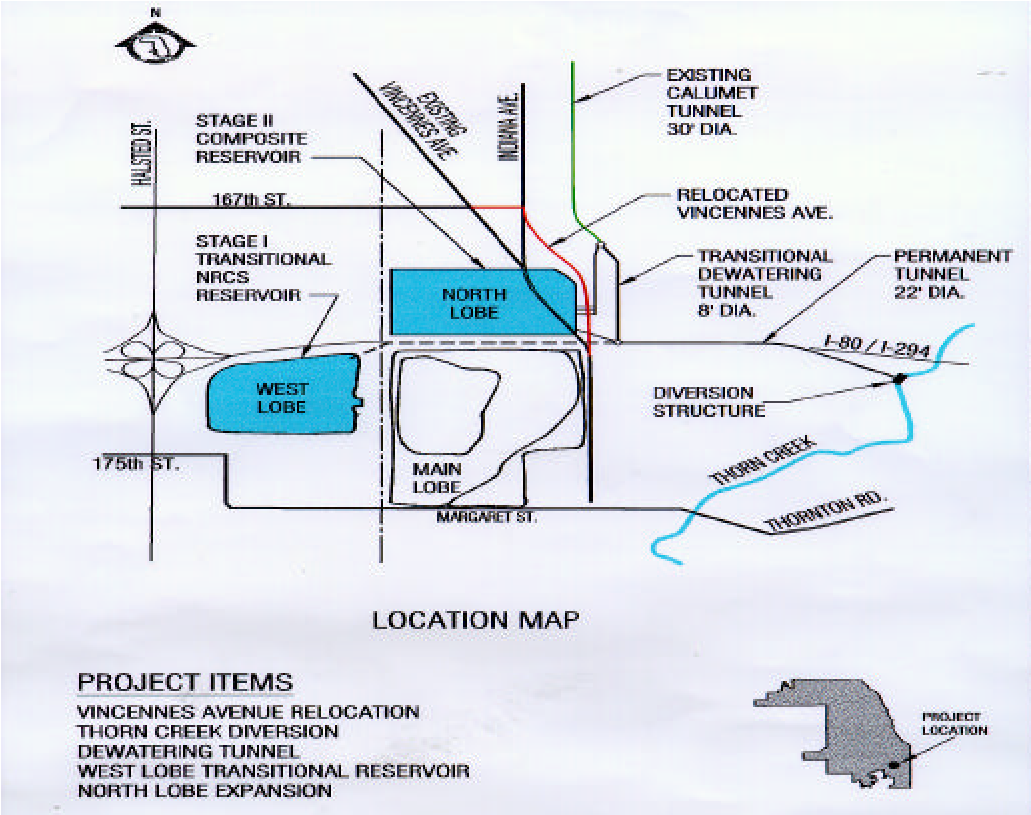

Figure 1. Thornton Reservoir Project (in final phase)

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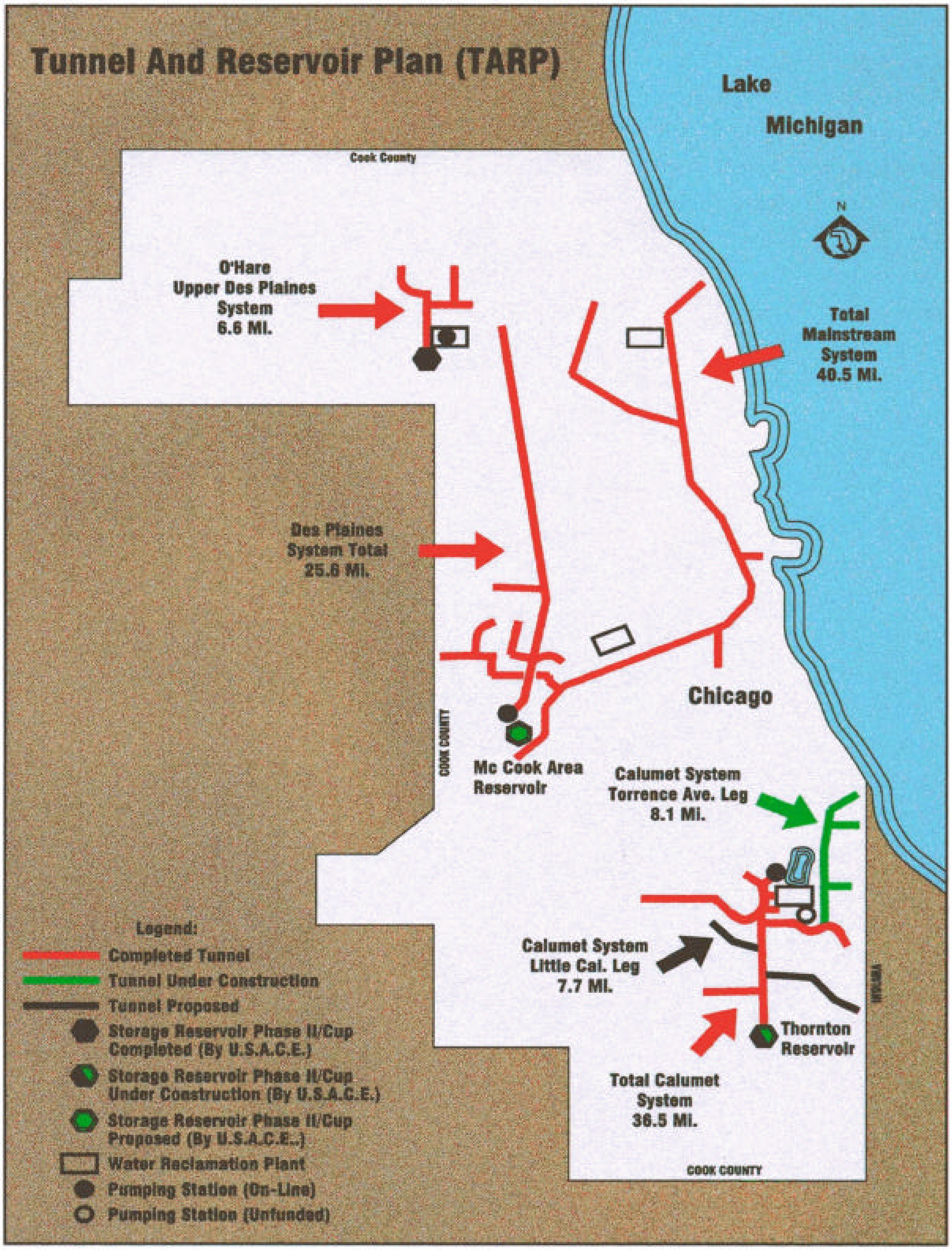


Figure 2. General schematics of Tunnel and Reservoir Plan (TARP) for stormwater management and water quality improvement in Chicago metropolitan area. Thornton Reservoir is the southern component of the TARP system

The TARP system consists mainly of two principal components:

a. The tunnels, which are associated primarily with water pollution control since they will convey the water stored in various reservoirs to the Water Reclamation Plants for cleaning and water quality improvement.
b. The reservoirs, which are associated primarily with the flood control in the Chicago Metropolitan area since they will store significant stormwater volumes during major flood events that will be slowly released after the flood peaks will recede.

The Thornton Transitional Reservoir is a first stage of the Thornton Composite Reservoir since it will use only the West Lobe of the Thornton Quarry. After the mining of North Lobe of the Quarry will be closed, the project will include and the North Lobe as part of the Thornton Composite Reservoir, the most southern component of the TARP system.

Thornton Transitional Reservoir will provide flood control in the Little Calumet River Watershed and will detain only stormwater. The project consists of several important components:

- The diversion structure that will divert over 80% of the 100-year peak discharge of Thorn Creek into a connection tunnel with variable width.
- The connection tunnel will convey the diverted water to an approximately 300 feet deep drop shaft, with a 24 foot diameter, that has at the lower end a deaeration chamber (L = 200 ft, W = 32 ft and H = 60 ft).
- The deaeration chamber that is connected to the 22 foot diameter diversion tunnel along I-80/I-294.
- The 22 foot diameter diversion tunnel that will convey the diverted water to the West Lobe of the Thornton Quarry, which will act as a storage reservoir during big flood events.
- The 8 foot diameter dewatering tunnel that will convey by gravity, the water stored in the quarry to the Calumet Water Reclamation Plant (CWRP) via the existing Calumet tunnel.

The design of these complex-function structures was accomplished using sophisticated 2-D hydraulic computation models, and advanced structural design methods. Details of this project and its overall positive effect on water quality are given in this paper.

DIVERSION STRUCTURE AT THORN CREEK

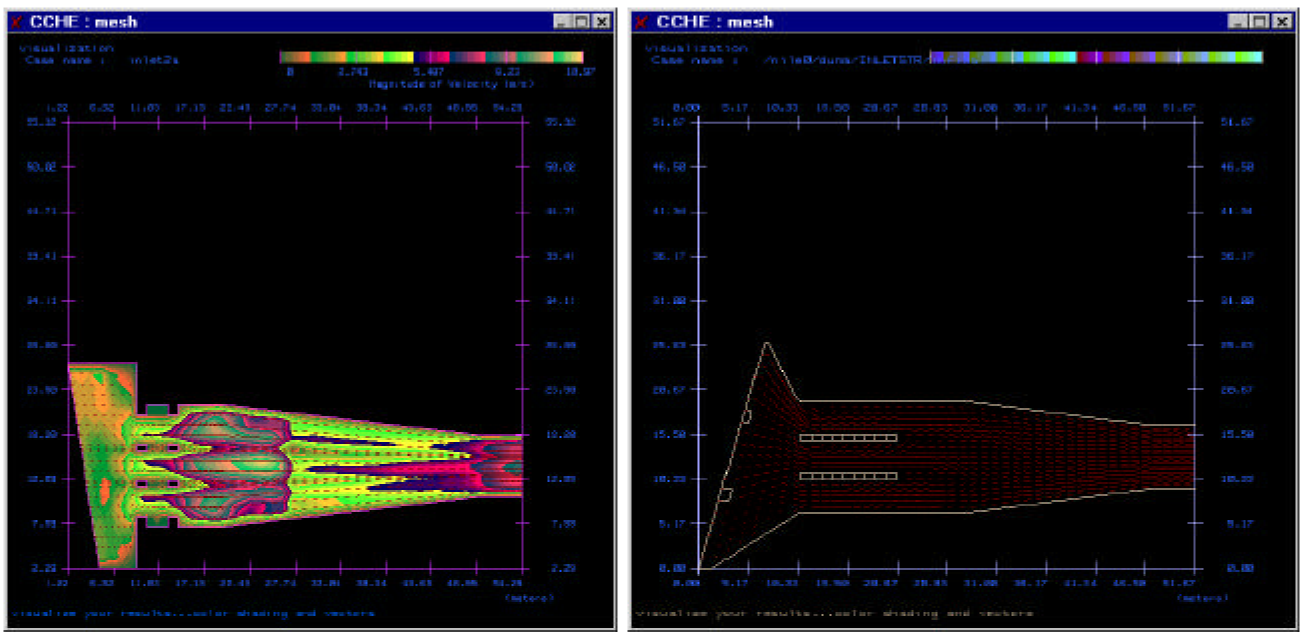
The existing flow conditions on Thorn Creek are mainly influenced by the water levels at its confluence with the Little Calumet River. Flow conditions along the channel reach in the area of the proposed diversion structure are characterized by relatively flat slopes and low flow velocities. In the proposed conditions, more than 80% of the 100-yr peak discharge of Thorn Creek will be diverted into the diversion structure. Significant flow regime changes on Thorn Creek would occur during a 100-yr flood event, as compared to the existing flow conditions, that mainly would consist of:

a. Decrease of water surface elevations of about 6.3 to 6.6 feet at the diversion structure, due to the reduction of the 100-yr peak discharge from 7400 cfs for existing conditions, to 1500 cfs under project conditions.

b. Increase of the longitudinal water surface slope along Thorn Creek, upstream of the diversion structure intake, from an average of 0.027% in existing conditions, to about 4.13% for the project conditions, with a peak diverted discharge of 6200 cfs.

Due to these changes of flow conditions, the flow velocity during the 100-yr flood event, along the Thorn Creek reach upstream of the diversion structure, would increase from approximately 3.0 ft/s under existing conditions, to approximately 12 - 14 ft/s under proposed conditions. In these conditions, some channel erosion could develop, in time, along the upstream reach of the creek, the extent of which would depend on the sediment characteristics of the channel bed.

The diversion structure at Thorn Creek was designed using a sophisticated 2-D computation model (CCHE2D) developed at the University of Mississippi [1]. The model was used to determine the optimum configuration of the diversion intake and the connection tunnel (Figures 3a and 3b) in order to convey the diverted storm water to the 300 feet deep drop shaft. The CCHE2D computation model is a depth-integrated two-dimensional hydrodynamic model that can be used for numerical simulation of steady and unsteady flows in rivers, basins and estuaries. This advanced computation model can accept, a "cold start" (i.e. zero flow velocity field) as well as a "hot start" (i.e. with flow velocity field obtained from previous calculations) as initial conditions. It also accepts a "dry bed" condition for starting computations, which is an advanced feature as compared to other similar computation models.



a. b.

Figure 3. Initial (a) and final (b) configuration of the intake/diversion structure and the connection tunnel to the drop shaft.

The diversion intake is designed to convey discharges up to 6700 cfs, which is 500 cfs more than the required design discharge of 6200 cfs. A sediment barrier wall (weir) of 83 feet in length, with top elevation above the normal water elevation in the creek, of 585.50 feet relative to National Geodesic Vertical Datum (NGVD) or 6.00 feet relative to Chicago City Datum (CCD)[3], in order to prevent potentially heavy bedload sediment from Thorn Creek entering into the structure.

[3] Elevation "0" CCD was approximated as 579.50 feet NGVD. The exact value is 579.48 NGVD.

The intake bay area, downstream of the entrance weir is at elevation 574.90 feet (NGVD) or - 4.6 feet (CCD) with a 2% bottom slope toward the gates. Three 12' x 12' sluice gates will control the flow into the connection tunnel to the drop shaft. The gates will be operated manually from the gatehouse, located on the top of structure, or remotely from the Calumet Water Reclamation Treatment Plant. The gatehouse floor elevation is above the existing condition 100-yr flood elevation. Due to the steep rise of the creek bank at this location, it was possible to locate the diversion structure in such way that most of the structure is underground; hence the natural esthetics of the area will not be adversely impacted. The intake structure is equipped with stop log supports to isolate the gates for routine maintenance and repair.

Since the structure is located in a Forest Preserve the stormwater could carry floating debris during floods. In order to prevent such debris from entering the structure, a curved alignment of 12" diameter pipes, at 3 feet center apart, was provided in front of the structure. This protection screen follows the existing curvature of the bank, so that the natural configuration of the channel will not be adversely impacted. In order to prevent intentional or accidental access into the diversion structure, a grate with 6"openings was provided at the entrance of the intake bay, on the top of the sediment barrier wall (weir). This feature prevents also pedestrians or animals from falling into the structure. An access road with a wider parking and maneuvering area ensures the access for service vehicles to clean up the collected debris in front of the structure and for periodic maintenance.

THE CONNECTION TUNNEL AND THE DROP SHAFT

As previously mentioned, the diverted water from Thorn Creek is conveyed through a connection tunnel with variable width into a 22 foot diameter drop shaft, approximately 300 feet deep, that has at the lower end a huge deaeration chamber (200 ft x 32 ft x 60 ft), connected to the 22 foot diversion tunnel that ends in the West Lobe of Thornton Quarry.

The CCHE2D computation model was used to analyze the flow pattern inside of diversion structure and the connection tunnel, and to design the optimum configuration of the entire structure. Based on the CCHE2D numerical modeling, the connection tunnel will be 12 feet in height with a tapered width, of 48 feet at the control gates to 24 feet at the drop shaft entrance. The longitudinal slope of the tunnel is 7% on a length of about 110 feet downstream of the gates. The downstream end of the tunnel, at the junction with the drop shaft, is rounded in order to ensure a proper hydraulic transition. As recommended by the U. S. Army - Corps of Engineers, the radius of rounding should be 1.5 Ht (where Ht - is the tunnel height). Therefore, for Ht = 12 feet, a rounded transition with a radius of 20 feet was designed at the downstream edge of the connection tunnel.

The maximum discharge capacity of the connection tunnel is 6700 cfs for a free flow condition. The flow in the connection channel is supercritical (i.e. Fr > 1.0), with flow velocities ranging from 15 ft/s, just downstream of the control gates, to 30 - 40 ft/s at the downstream end of the tunnel. The nappe for the design discharge, at the downstream end of the connection tunnel to the drop shaft will hit the drop shaft wall at an angle of about 25 to 29 degrees, hence no special construction measures were needed to protect the wall. The water impact point would be approximately elevation 527.00 feet NGVD (i.e. elevation - 52.5 feet CCD) which is 20 feet below the downstream edge of the connection tunnel.

THE DIVERSION TUNNEL

The deaeration chamber at the lower end of the drop shaft (that will prevent the air entertained in the drop shaft from entering into the tunnel) is connected to a 22 feet diameter diversion tunnel machine bored in rock, along interstate I-80/I-294, approximately 300 feet below the surface of ground. In the first stage of the project, the diverted Thorn Creek stormwater will be conveyed to the West Lobe of the quarry. The diversion tunnel has a double function: diversion of Thorn Creek stormwater into the quarry, and draining the reservoir to the Calumet Water Reclamation Treatment Plant (CWRP) through the Calumet (TARP) tunnel. To accomplish the dewatering, an 8 foot diameter drain tunnel, connected to the main diversion tunnel just east of Vincennes Avenue, will convey gravitationally the water stored from the West Lobe reservoir to the CWRP. The dewatering tunnel empties to a valve shaft with two 42" hydraulically operated cone valves to regulate the discharge of water to the CWRP and to prevent back flow of combined sanitary and stormwater flow from the Calumet TARP System.

THE RESERVOIR AND WATER QUALITY ENHANCEMENT

The Thornton Transitional Reservoir will occupy only the West Lobe of the quarry, as a first stage of the final project of Thornton Composite Reservoir. The reservoir will provide flood storage of the 3.1 billion gallons of water from Thorn Creek during floods. After the peak flood stages in Thorn Creek and Calumet River will recede, the reservoir will be gravitationally dewatered through the Calumet TARP System to the Calumet Water Reclamation Plant (CWRP). After dewatering, sediment and other debris that were settled in the reservoir will be disposed to off-site. Therefore, the Thornton Transitional Reservoir project has a double role: flood protection and water quality improvement for an area of approximately 300 square miles, which includes parts of the City of Chicago and its southern suburbs.

SEDIMENT TRANSPORT AND BANK PROTECTION

The flow regime and the sediment transport on Thorn Creek during floods exceeding 1500 cfs would be significantly impacted by the operation of the diversion structure. A sediment transport analysis for the Thorn Creek reaches adjacent to the proposed diversion structure was performed using the results of the CCHE2D hydraulic computation model (Figure 4), and the results of the grain size analysis of the sediment samples collected from the channel.

The total sediment load (g_s) on Thorn Creek for the proposed conditions was estimated using the relation proposed by Grade – Albertson [2], which appears to give the most reasonable results:

$$g_s = (1.36\, V^4\, n^3) / \{[\nu(10^5)]^3\, (D_{50})^{3/2}\, H\}$$

where

V	– is the flow velocity
D_{50}	– is the median sediment size
H	- is the water depth
n	- is the roughness coefficient
ν	- is the settlement velocity for the sediment

The numerical simulations performed using the CCHE2D computation model were compared with analytical calculations. The results showed good agreement. Figure 4 presents the flow velocity distribution in the Thorn Creek reach influenced by the diversion structure operation

Based upon the results of the analysis, the sediment transport on Thorn Creek could be significantly influenced during the operation of the diversion structure. However, the sediment transport analysis was done considering that the design discharge lasts until equilibrium conditions for sediment transport occur. Since the time duration for the entire 100-yr flood on Thorn Creek is generally only two days, the equilibrium sediment transport conditions will be reached only for a very short time interval. Therefore, the sediment transport on Thorn Creek could be less affected than predicted by the sediment transport analysis. However, a program to monitor channel stability and sediment transport upstream and downstream of the diversion structure will be implemented after completion of project.

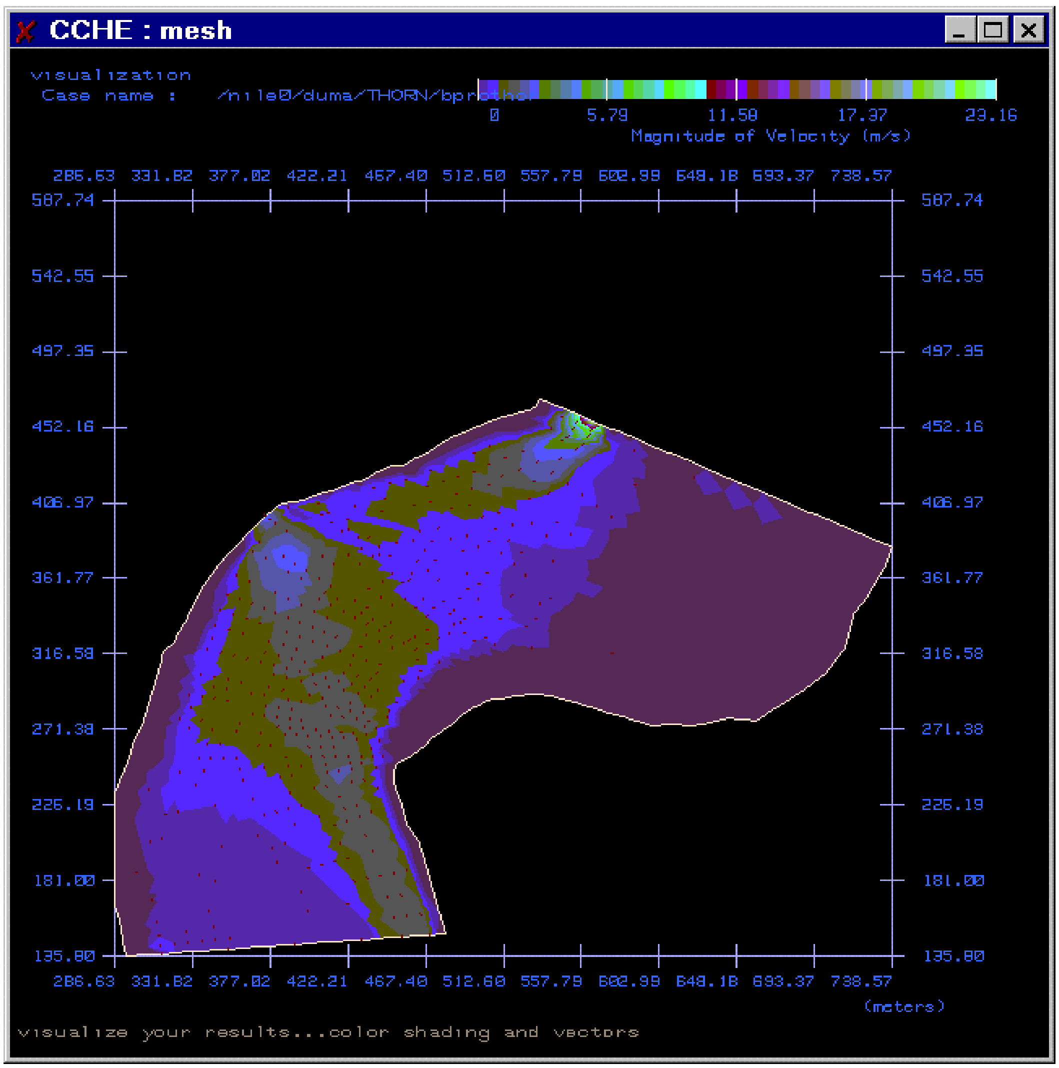


Figure 4. Flow velocity distribution in Thorn Creek (CCHE2D numerical simulation)

In addition, erosion control measures for bank protection upstream and downstream of the proposed diversion structure were provided.

CONCLUSIONS

The project is now under construction (Figure 5), and will be completed at the beginning of 2003. As part of TARP system, Thornton Transitional Reservoir will contribute to mitigation of the flooding potential, and will improve the water quality of the natural waterways in the Chicago Metropolitan area.

Figure 5. Diversion structure at Thorn Creek during construction

REFERENCES

1. Yafei Jia and Sam S.Y. Wang: "*CCHE2D – A Two-Dimensional Hydrodynamic and Sediment Transport Model for Unsteady Open Flows Over Loose Bed*", National Center for Computational Hydroscience and Engineering, Technical Report No. CCHE-TR-97-2, September 1997

2. Garde, R. J., Albertson, M. L.: "*The Total Sediment Load of Streams*", Journal of the Hydraulics Division, ASCE, Paper 1856, November 1958, pp 59-79